

Name: Michael U. Rudolphi

Title: Recovery of Space Shuttle *Columbia* and Return to Flight of Space Shuttle
Discovery

Organization: NASA

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Degrees: BS and MS, Civil Engineering, University of Tennessee

Position: Director, Engineering Directorate, Marshall Space Flight Center

NASA has come a long way in our journey to reduce the risks of operating the Space Shuttle system. The External Tank bipod Thermal Protection System has been redesigned to eliminate the proximate cause of the *Columbia* accident. In all areas, we have applied the collective knowledge and capabilities of our Nation to comply with the *Columbia* Accident Investigation Board recommendations and to raise the bar beyond that. We have taken prudent technical action on potential threats to review and verify the material condition of all critical areas where failure could result in catastrophic loss of the crew and vehicle. We are satisfied that critical systems and elements should operate as intended—safely and reliably. While we will never eliminate all the risks from our human space flight programs, we have eliminated those we can and reduced, controlled, and/or mitigated others. The remaining identified risks will be evaluated for acceptance. Our risk reduction approach has its roots in the system safety engineering hierarchy for hazard abatement long employed in aerospace systems engineering. The components of the hierarchy are, in order of precedence, to: design/redesign; eliminate the hazard/risk; reduce the hazard/risk; and control the hazard/risk and/or mitigate the consequence of the remaining hazard/risk through warning devices, special procedures/capabilities, and/or training. This proven approach to risk reduction has been applied to potential hazards and risks in all critical areas of the Space Shuttle and has guided us through the technical challenges, failures, and successes present in return to flight endeavors. This approach provides the structured deliberation process required to verify and form the foundation for accepting any residual risk across the entire Space Shuttle Program by NASA leadership.

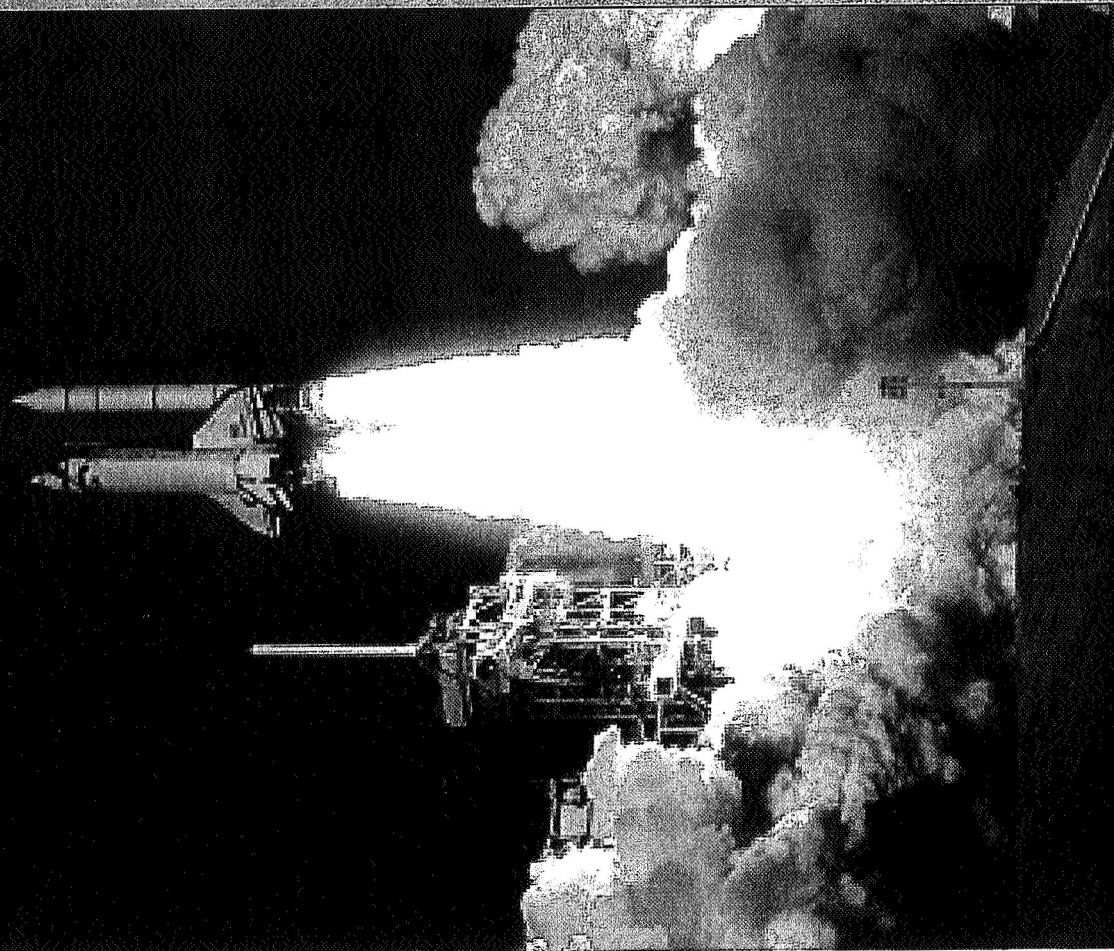


Recovery
of
Space Shuttle
Columbia

and

Return to Flight
of
Space Shuttle
Discovery

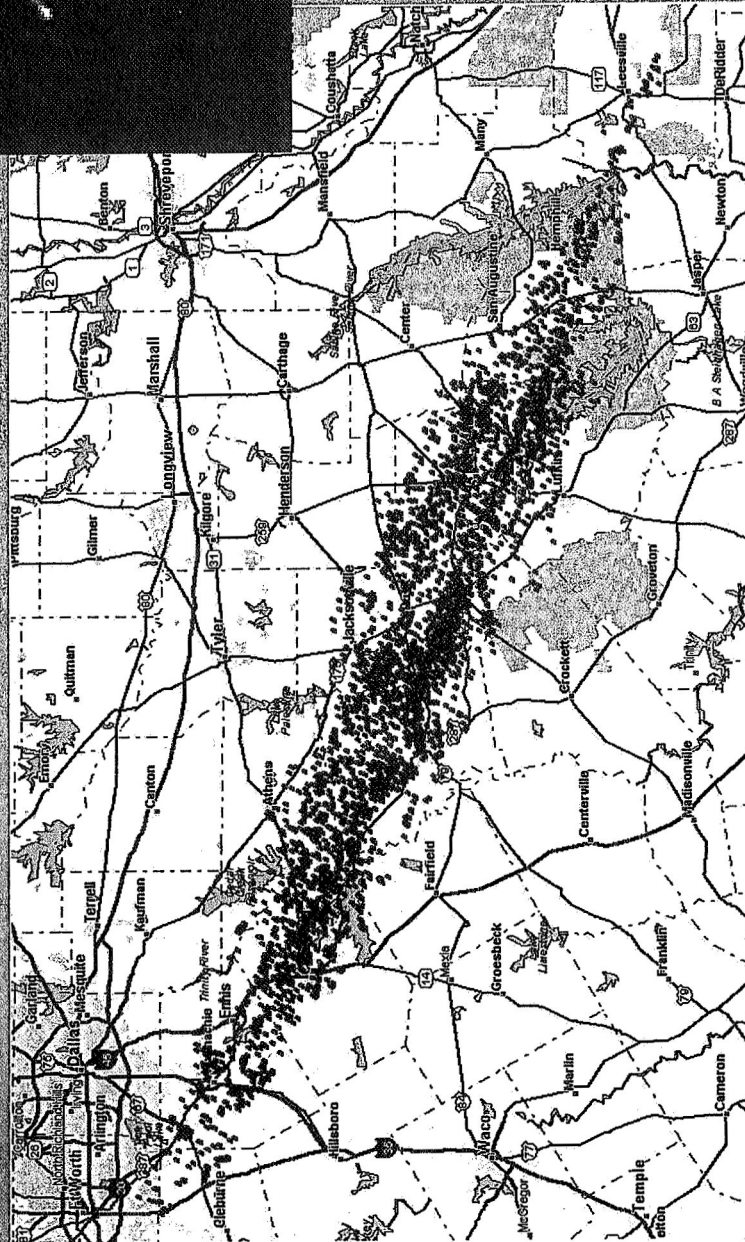
Michael U. Rudolph
Engineering Director
Marshall Space Flight Center



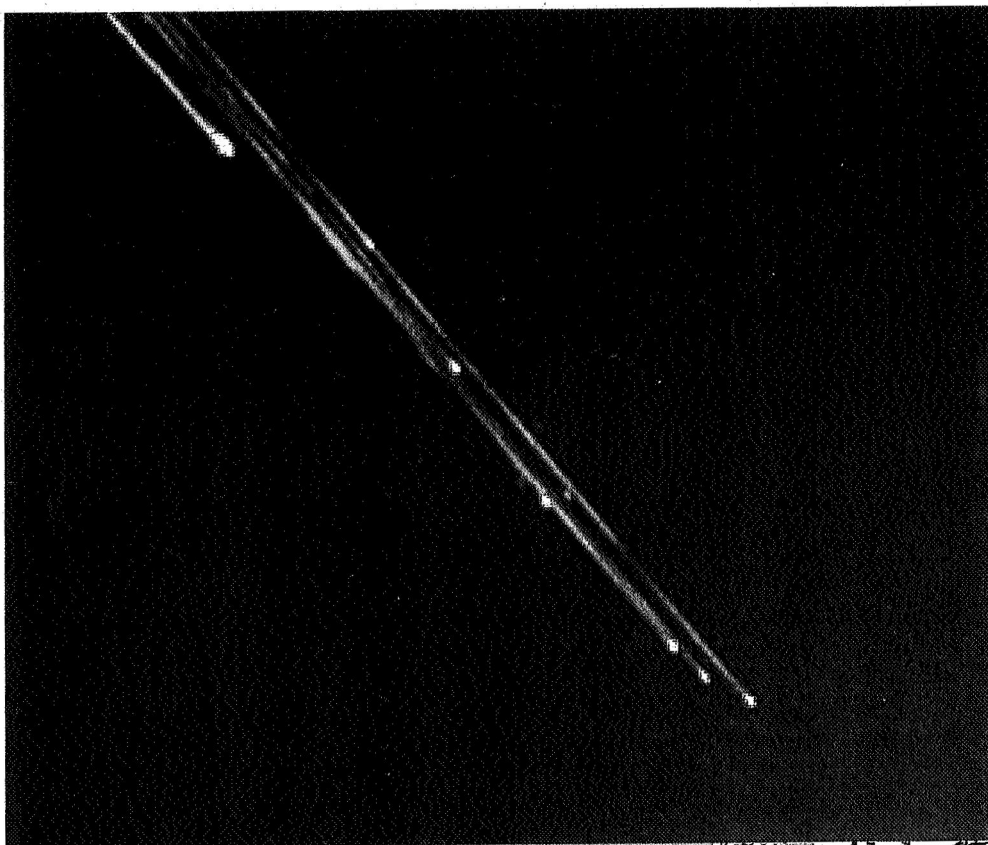


On February 1, 2003, Space Shuttle
Columbia and her crew were lost
upon re-entry during STS-107.

The debris field ranged from eastern
Texas to western Louisiana.



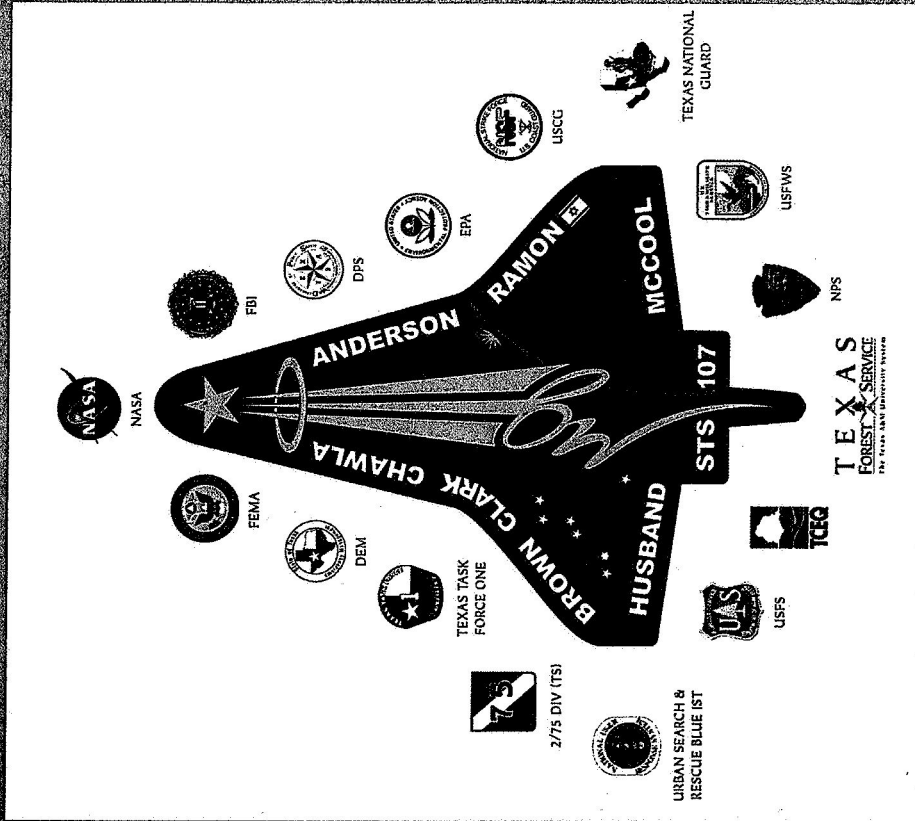
Radar - derived
debris plot



Multi-Agency response to a monumental challenge

NASA

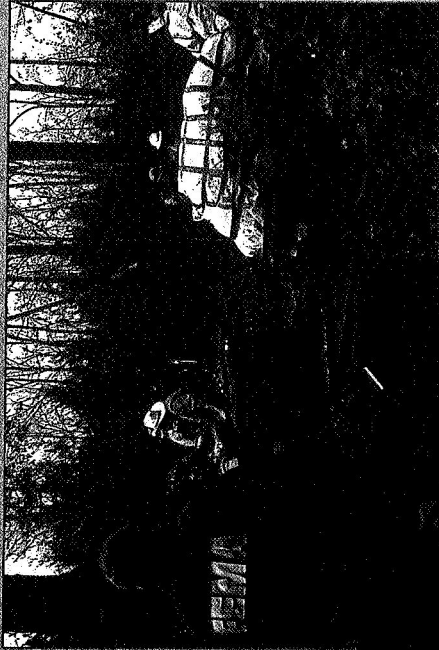
- ★ Disaster field offices (DFO's) were established at Barksdale AFB, LA and Lufkin and Ft. Worth, TX.
- ★ More than 25,000 people were actively involved in search efforts. Over 480 Federal, state, and local agencies (as well as private organizations and volunteer groups) provided search personnel, supplies, and equipment.
- ★ Debris field included
 - ✓ Area about the size of Rhode Island
 - ✓ Main corridor ~10 miles wide and 240 miles long, stretching from Dallas, TX to Fort Polk, LA
 - ✓ 8 counties inhabited by over 400,000 people (none injured by falling debris)





Goals

- ★ Ensure public safety.
- ★ Recover crew.
- ★ Retrieve evidence.
- ★ Compensate costs incurred by local jurisdictions.



Ground search

NASA

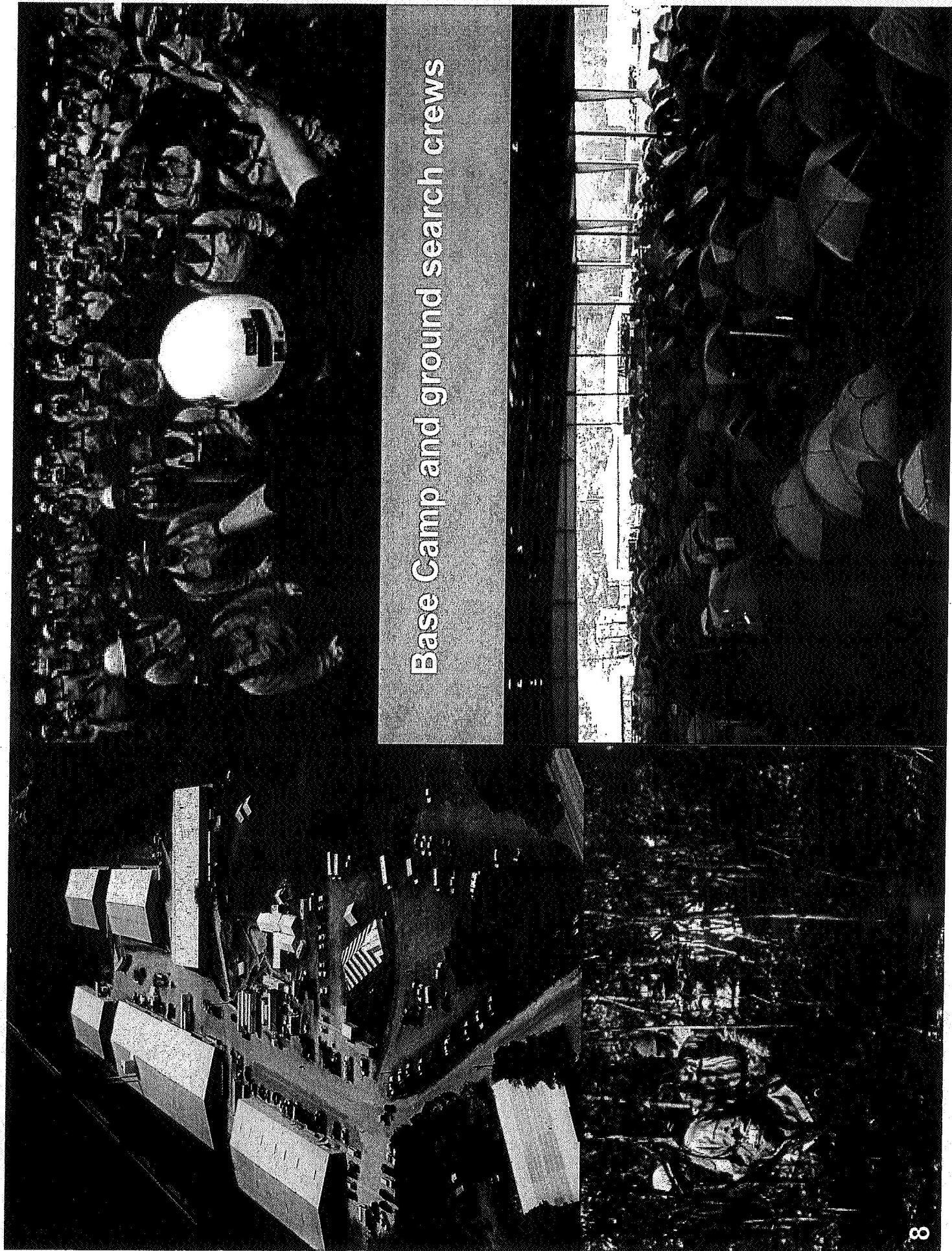
★ Searched

- ✓ 680,748 acres (total)
- ✓ 9,800 acres per day (average)
- ✓ 4.4 acres per day per searcher (average)

★ To date

- ✓ 82,300 out of 222,900 lbs recovered
(~38% total re-entry weight of Space Shuttle Columbia)
- ✓ Over 81,965 pieces retrieved during search
- ✓ 66,895 pieces identified at Kennedy Space Center

Base Camp and ground search crews



Water Search

NASA

★ Dive Teams

- ✓ US Navy Salvage Team
- ✓ US Coast Guard Team
- ✓ FBI Dive Team
- ✓ DPS Dive Team
- ✓ Houston Police Dive Team
- ✓ Galveston Dive Team

★ Total area scanned

- ✓ 14.69 sq. miles in Toledo Bend Reservoir
- ✓ 3.17 sq. miles in Lake Nacogdoches



★ Boats

- ✓ 13 dive boats
- ✓ 12 security boats
- ✓ 10 sonar boats

★ Dives

- ✓ 3,100 targets cleared in Toledo Bend Reservoir
- ✓ 365 targets cleared in Lake Nacogdoches

★ Sonar types used

- ✓ Multi-beam
- ✓ Side scan

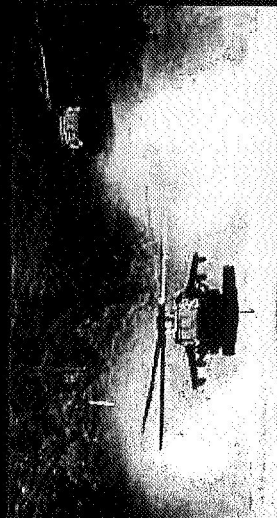
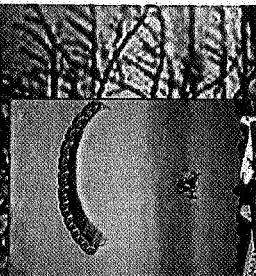
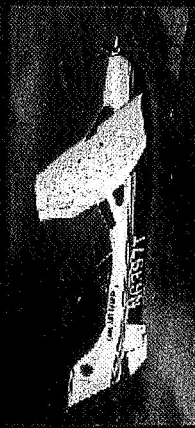
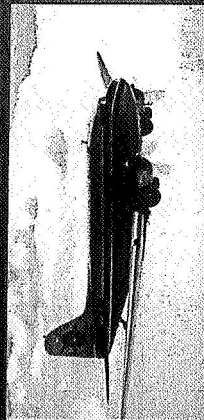
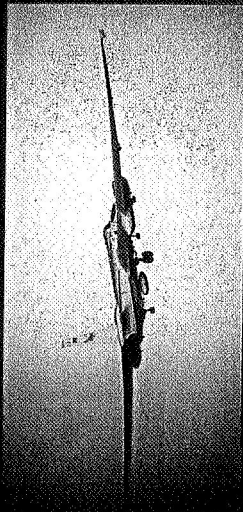
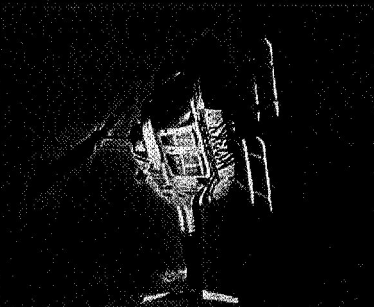
★ Personnel involved per day: up to 166

★ Bottom time: 800 hours total

Air search



- ★ Helicopters
- ★ Fixed wing aircraft
- ★ DC-3 aircraft
- ★ Civil Air Patrol
- ★ Department of Defense
- ★ NASA ER-2 (U-2 jet)
- ★ Motorized paragliders



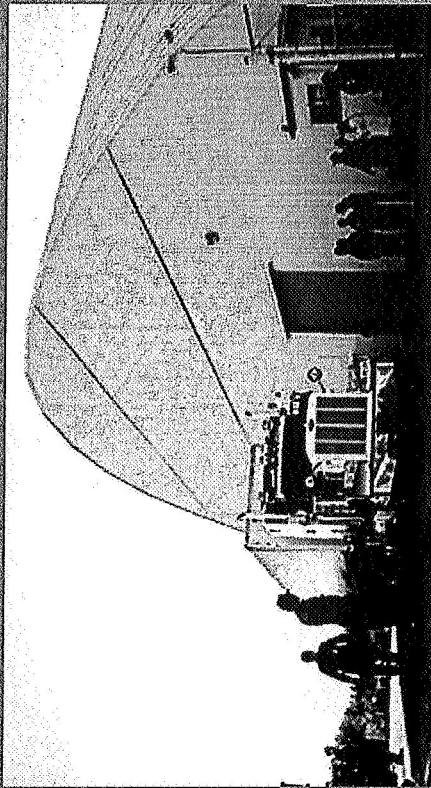
Monomethyl hydrazine spherical tank



Decontamination setup



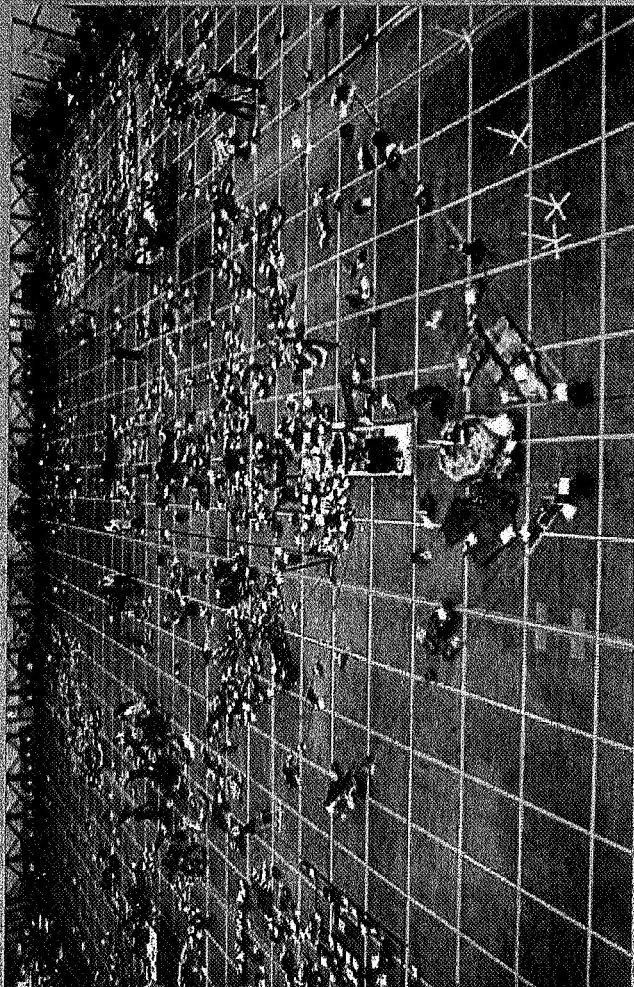
Reassembling the pieces



All retrieved material shipped:

★ first to Barksdale AFB or Johnson
Space Center

★ then to Kennedy Space Center

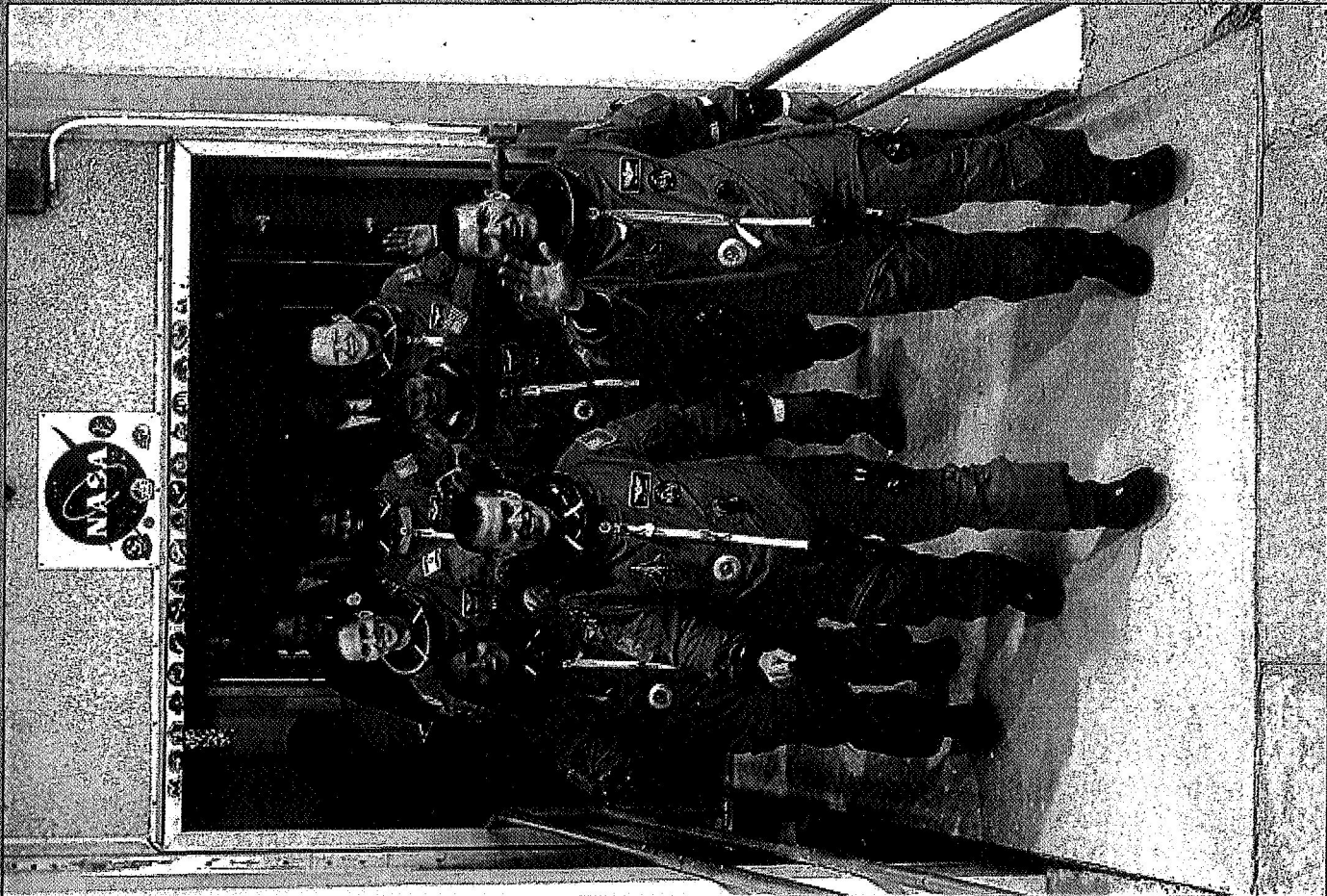


Why *Columbia* recovery succeeded

NASA

- ★ High-quality, capable, compatible people
- ★ Clearly articulated missions, strong universal buy-in
- ★ Trust built through transparency of leadership
- ★ Local capability, community generosity
- ★ Powerful support for NASA and the space program
- ★ No ongoing threat to life or property
- ★ Openness of physical space
- ★ Constituent units empowered
- ★ Accountable, but not overly rule-bound
- ★ Negotiated competing missions, lack of "turf" struggles
- ★ Explicit attention to morale





In Memoriam

Commander:
Rick Husband

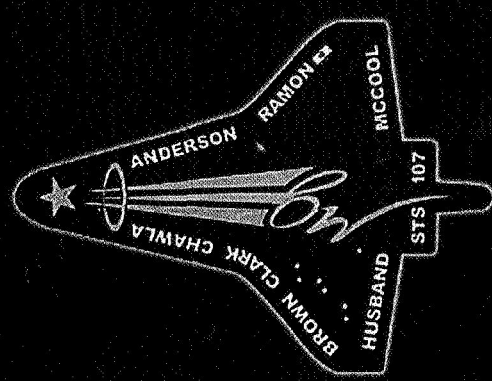
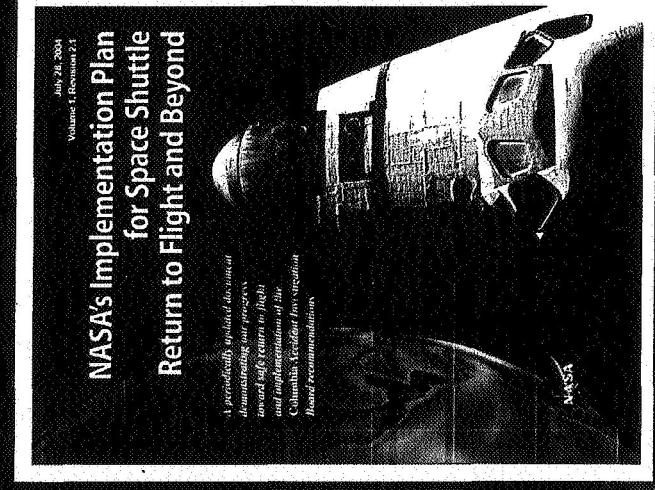
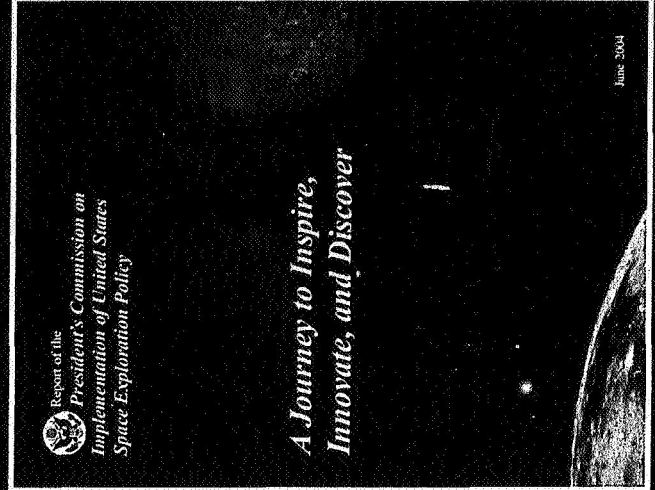
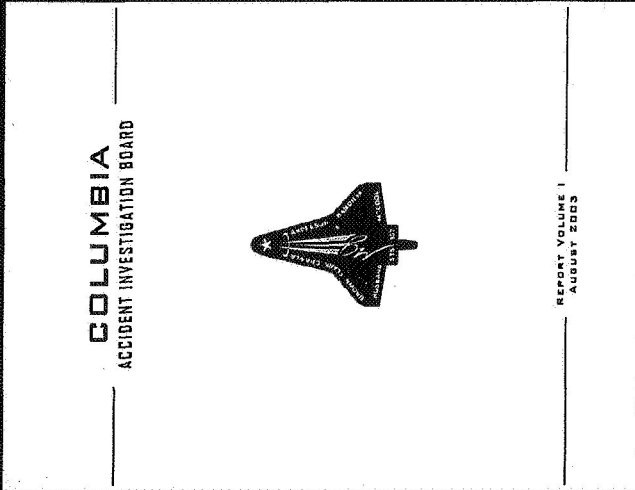
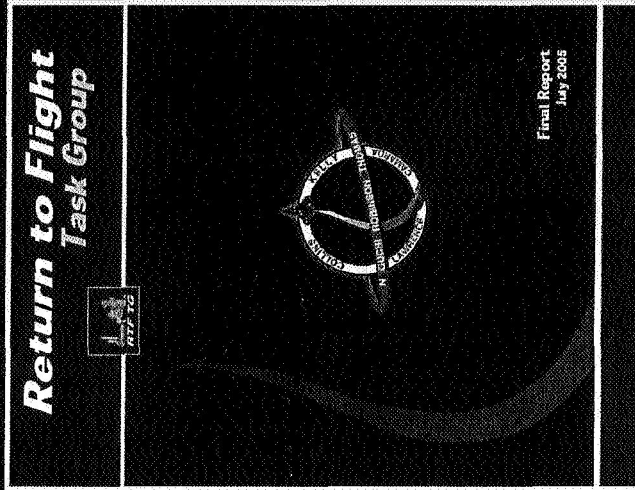
Pilot:
William McCool

Mission specialists:
Mike Anderson
David Brown
Kalpana Chawla
Laurel Clark

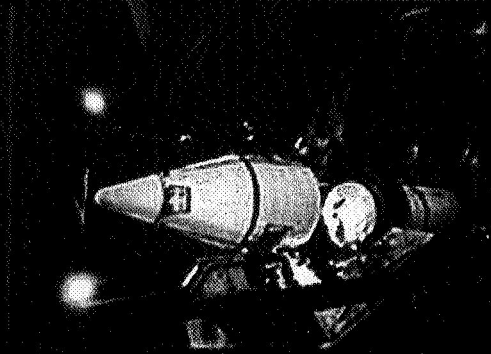
Payload specialist:
Ilan Ramon (Israel)

Lost during recovery effort:
Jules "Buzz" Mier, Jr.
Charles Krenek

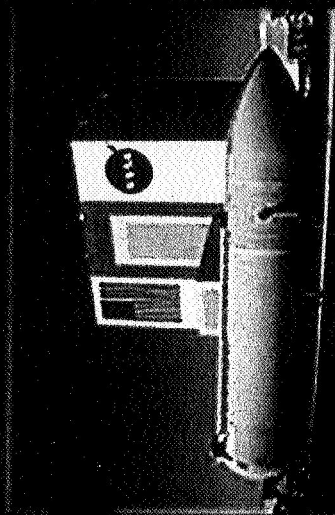




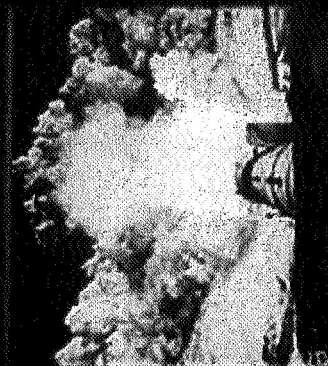
Return to Flight



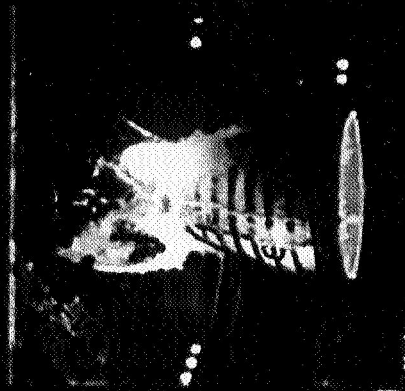
Reusable Solid Rocket Booster



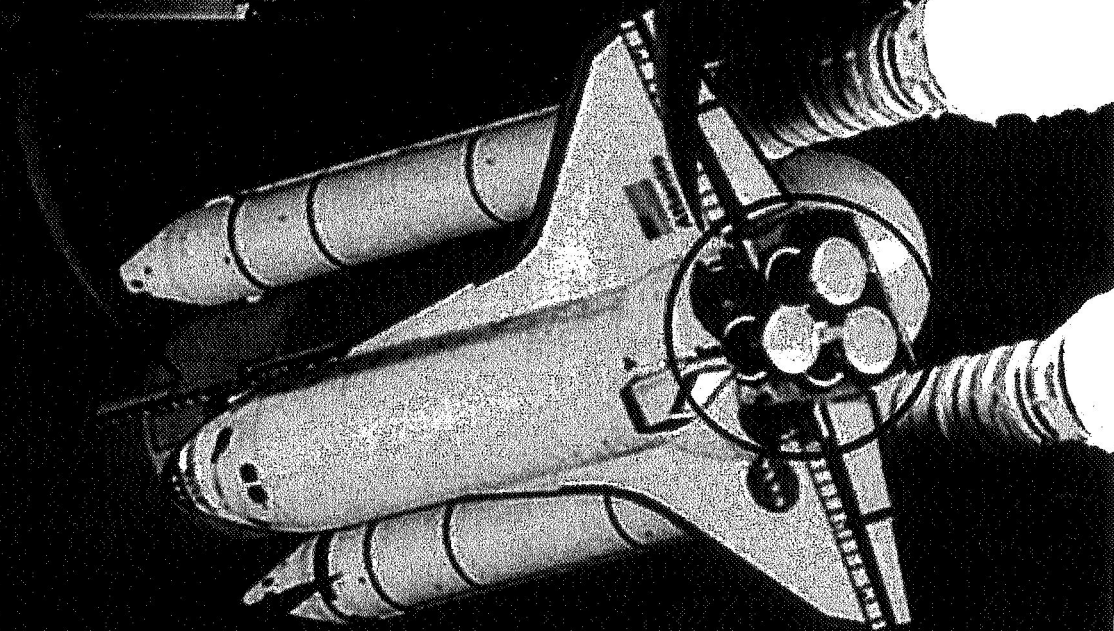
External Tank



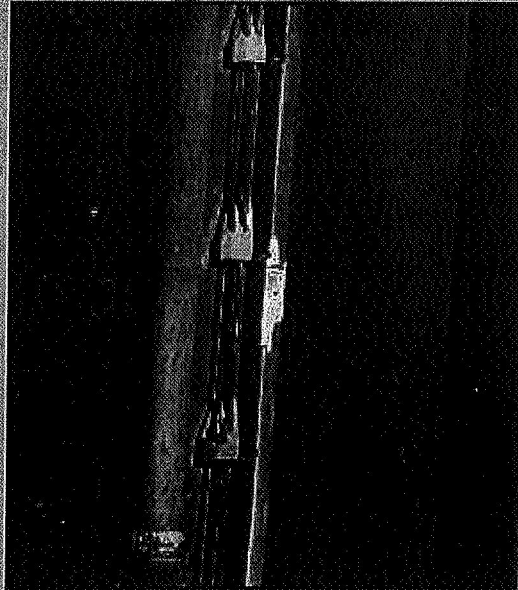
Reusable Solid Rocket Motor



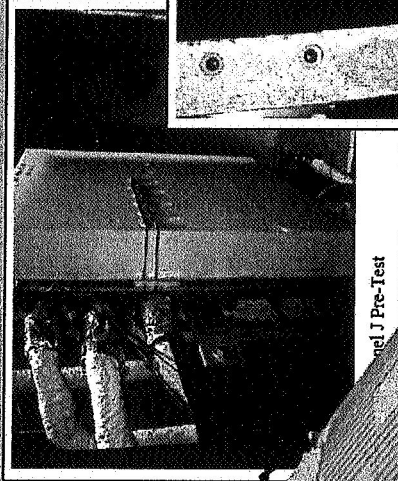
Space Shuttle Main Engine



ET/TPS Return to Flight - Development



This image shows a large piece of foam that separated from the ET during STS-114.



Cryogenic-Critical Defect Determination

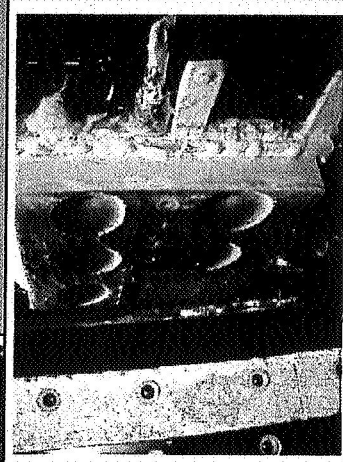
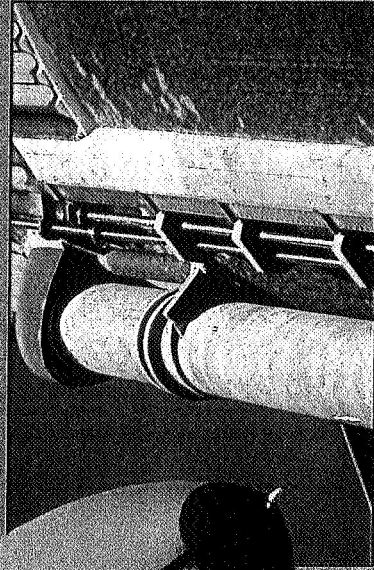
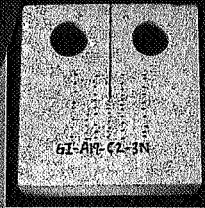


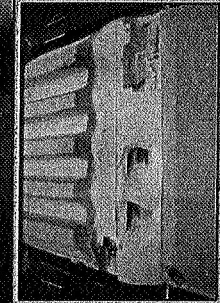
Figure 9.13. Panel J Post-Test 08/27/04



Bellows Ice Mitigation



TPS Fracture Toughness



Root Cause Testing

STS-121 / ET-119

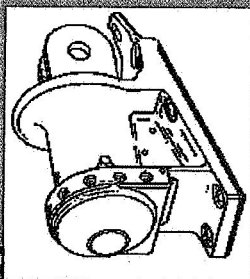
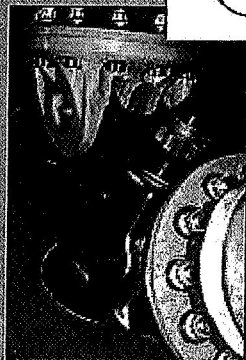
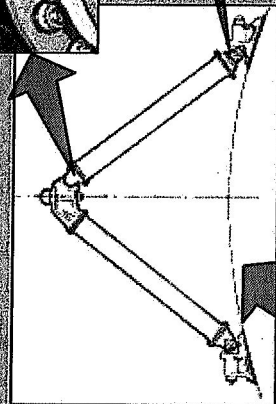
Return to Flight Modifications



Bipod Harness Revisions



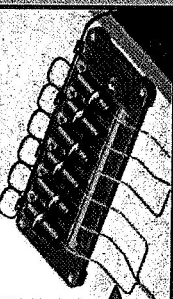
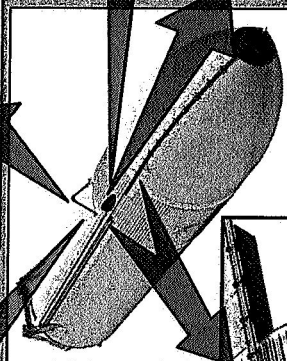
Bipod Hardware Revisions



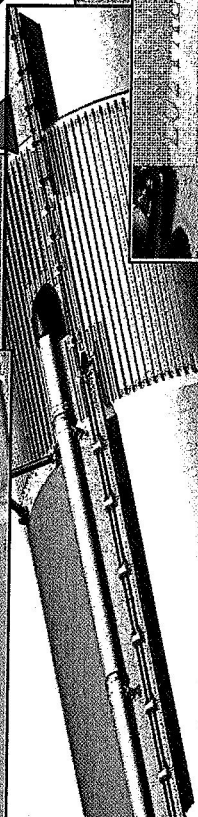
LO2 and LH2 PAL Ramp Elimination



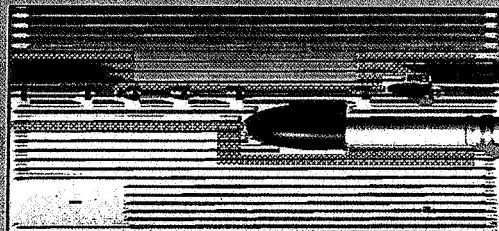
LH2 PAL Ramp



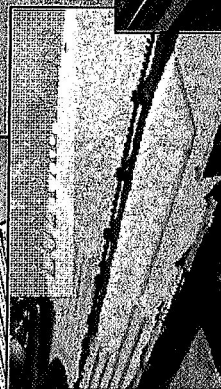
Development Flight Instrumentation



Inter-tank Acreeage Machining / Venting



Ice Frost Ramp



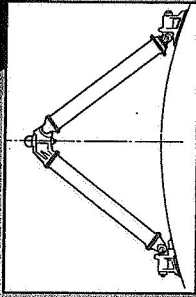
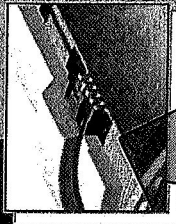
STS-114 / ET-121 Return to Flight Modifications



*Remove/Replace
Longeron Closeouts*



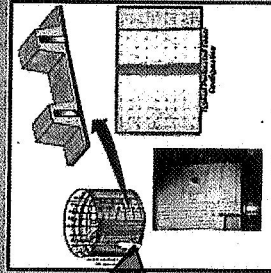
*L02 Feedline Bellows
TPS Drip Lip and
* Fwd Bellows Heater System*



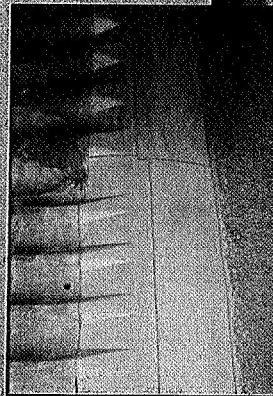
*Bipod Strut Hardware
(Lubricated thru-bolts)*



*Redesigned
Bipod Fitting*



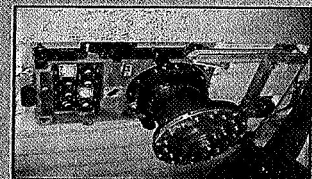
*Increase Area of
Vented Intertank TPS*



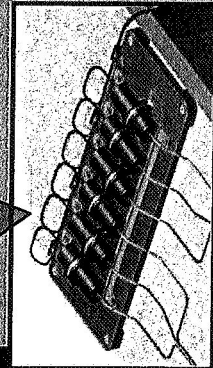
*Intertank / LH2 Tank
Flange Closeout
Enhancement*



*Partial LH2 PAL Ramp
Replacement*



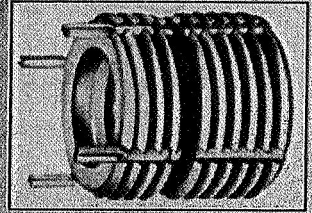
*ET Ground
Umbilical Redesign*



*RTF
Instrumentation*



*ET Camera in L02
Feedline Fitting*



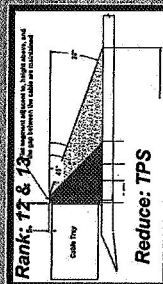
*ET/SRB
Bolt
Catcher
Inserts*

** Delta from RTF Baseline -
Not reviewed at SSP DCR*

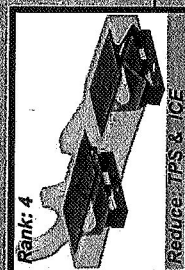
ET - Future Risk Reduction Redesign Initiatives



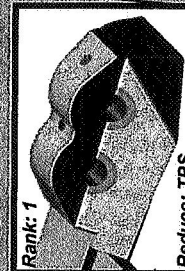
STS Launch Order	External Tank Delivery Order
STS116	ET-123
STS117	ET-124
STS118	ET-127
STS120	ET-120
STS122	ET-125
STS123	ET-126
STS124	ET-128
STS125	ET-129
STS119	ET-127
STS126	ET-130
STS127	ET-131
STS128	ET-132
STS129	ET-133
STS130	ET-134
STS131	ET-135
STS132	ET-136
STS133	ET-137



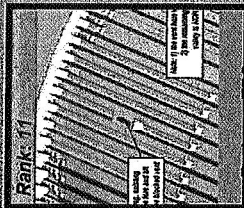
Rank: 12 & 13: Improved External Tank Delivery Order and External Tank Delivery Order. Reduce: TPS



Rank: 4: LH2 IFR Long Term. Reduce: TPS & ICE



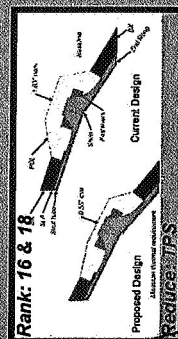
Rank: 1: LH2 IFR Interim. Reduce: TPS



Rank: 11: +Z Aerovent. Reduce: TPS



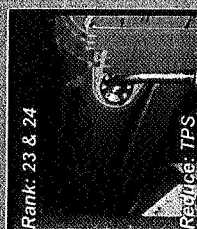
Rank: 10: LO2 / Inter-tank IFR. Reduce: TPS



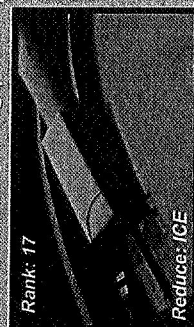
Rank: 16 & 18: Thrust Strut Flange: OML Change. Reduce: TPS



Rank: 19: Vertical Strut TPS. Reduce: TPS



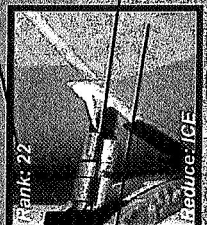
Rank: 23 & 24: Aft GH2 Press Line Fitting. Reduce: TPS



Rank: 17: Diagonal Strut Closeout. Reduce: ICE



Rank: 15: Umbilical Cable Trays. Reduce: TPS



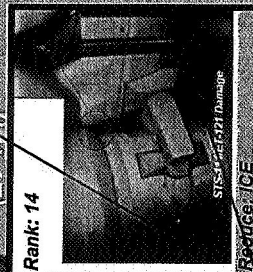
Rank: 22: Aft Lower ET/SRB Fittings. Reduce: ICE



Rank: 5 & 9: LO2 F/L Bellows Heaters. Reduce: ICE



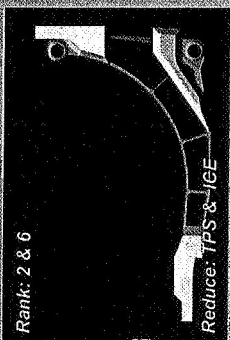
Rank: 3 & 7: LO2 F/L Strut. Reduce: TPS & ICE



Rank: 14: LO2 F/L & Flange Interference. Reduce: TPS & ICE



Rank: 2: LO2 Feedline (F/L) Base Closeout. Reduce: TPS & ICE



Rank: 2 & 6: LO2 Feedline T/J Yoke. Reduce: TPS & ICE

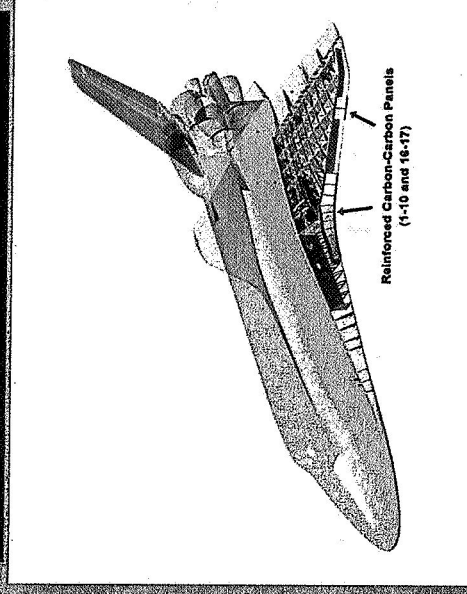
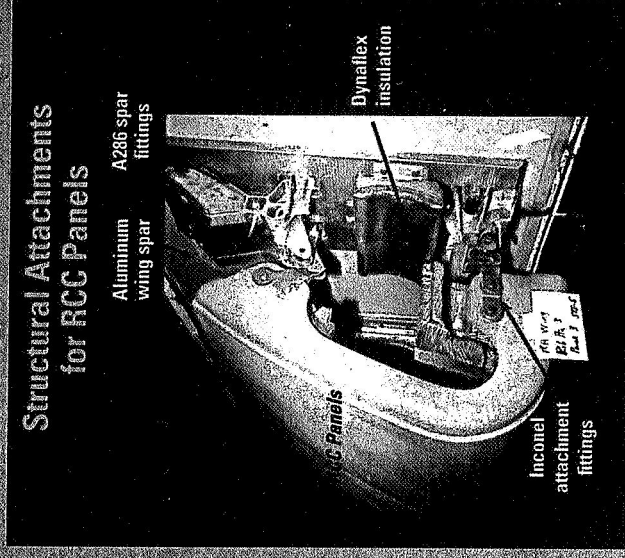
Ranking and ET Implementation based on SDS 6123

Several significant redesign initiatives have already been identified and prioritized.

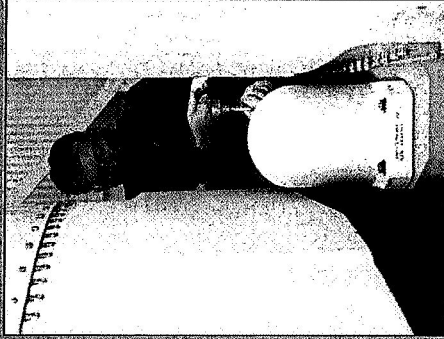
RCC nondestructive evaluation and TPS repair



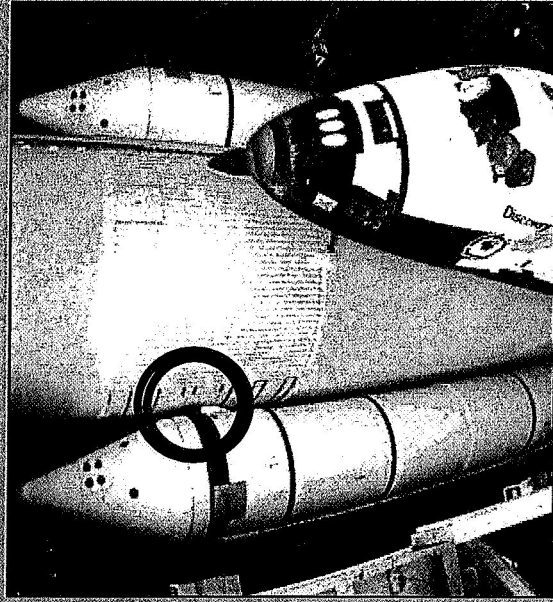
- Removed all noscap, chin panel, and wing leading edge RCC panels from each Orbiter.
- Returned to the manufacturer for evaluation.
- Testing methods included same evaluations done during the original acceptance testing, as well as new technologies developed since then.
- Still working on repair capability for TPS tile and RCC panels.
- Each technique must be tested and verified.
- Not considered sufficiently mature to be practicable for remaining Shuttle flights.



SRB bolt catcher

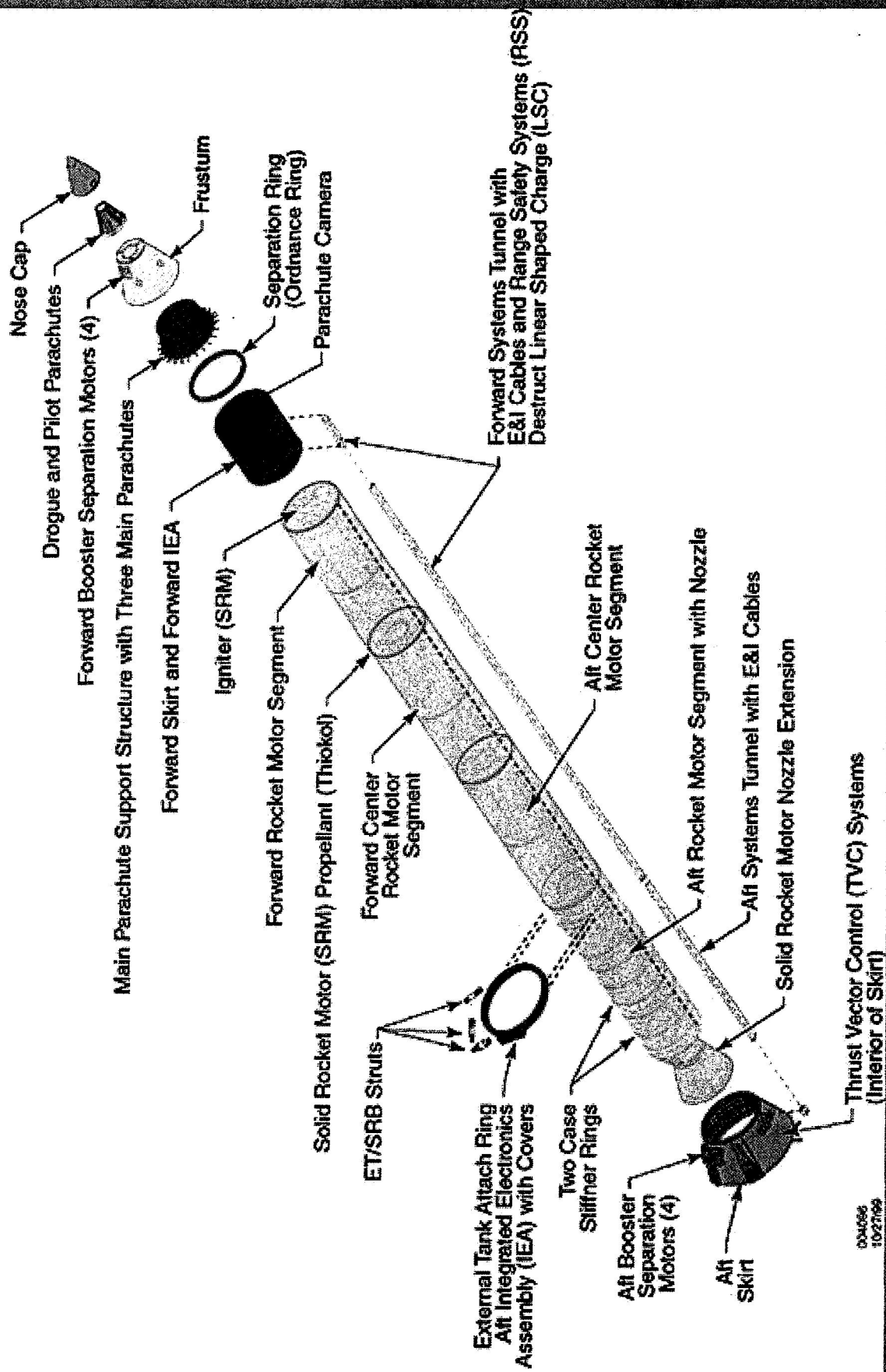


- Original design load did not include dynamic effects on energy absorber crush strength.
- Possible debris sources included SLA-561 thermal protection material, attach fasteners, or insert failure.
- New design uses cork as TPS material and has passed factor of safety testing.



SRB Schematic

NASA



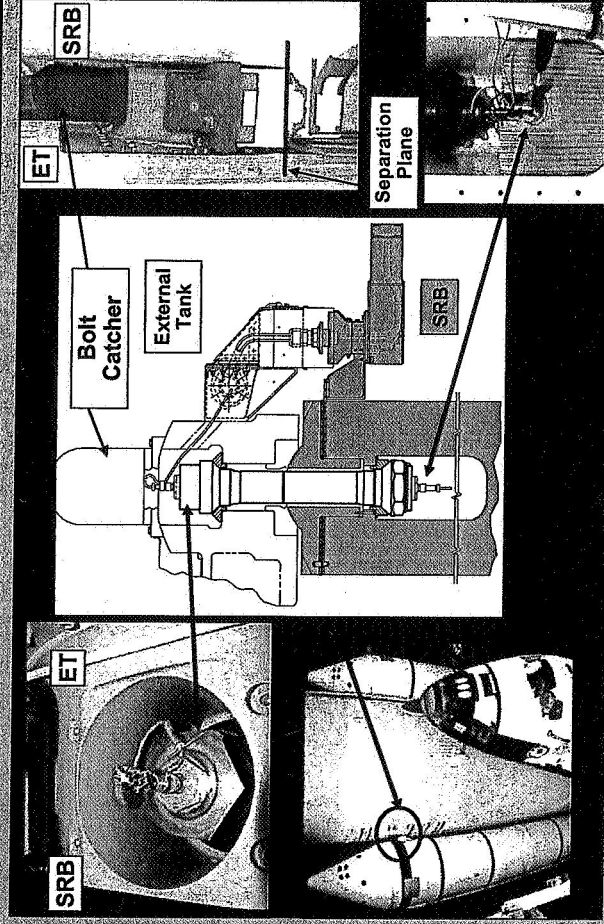
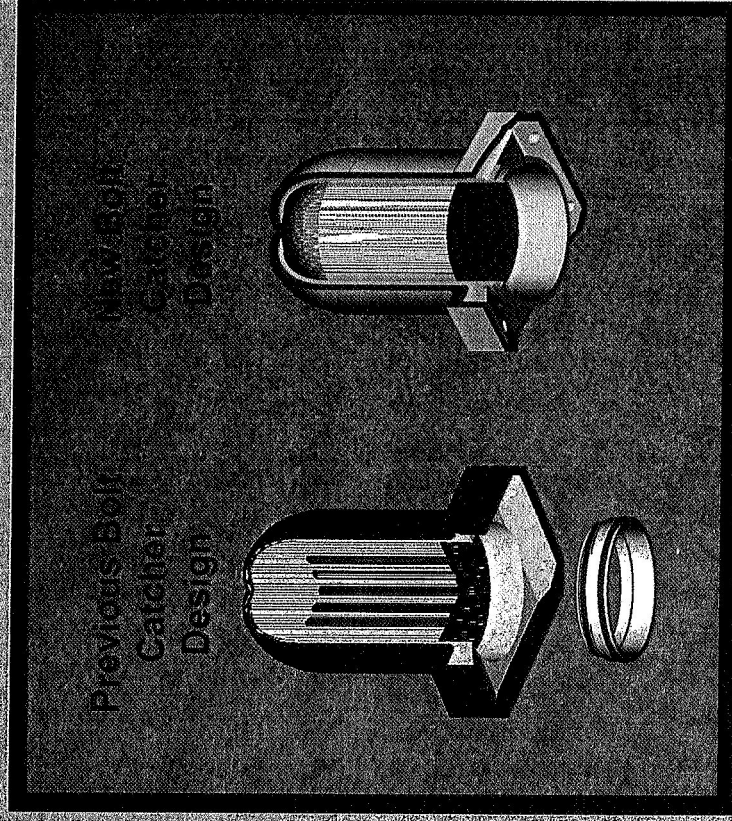
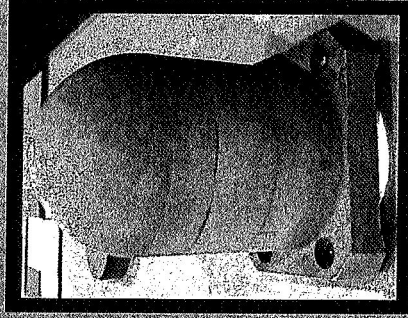
000066
10/27/99

SRB Return to Flight

Bolt Catcher NSIPC Redesign

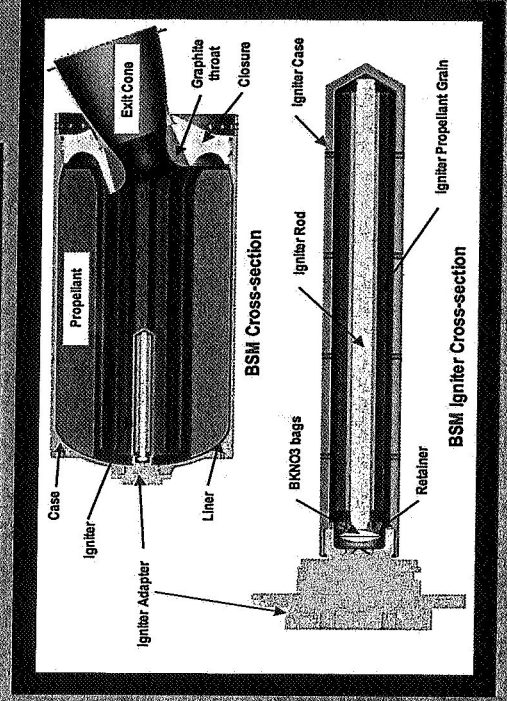
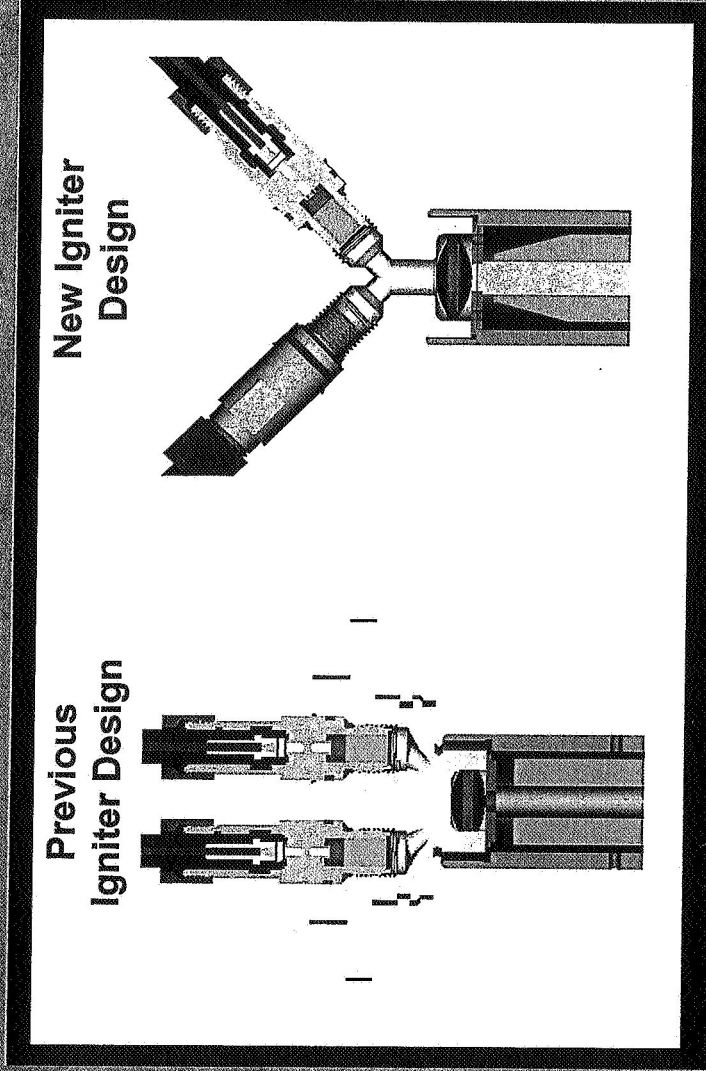
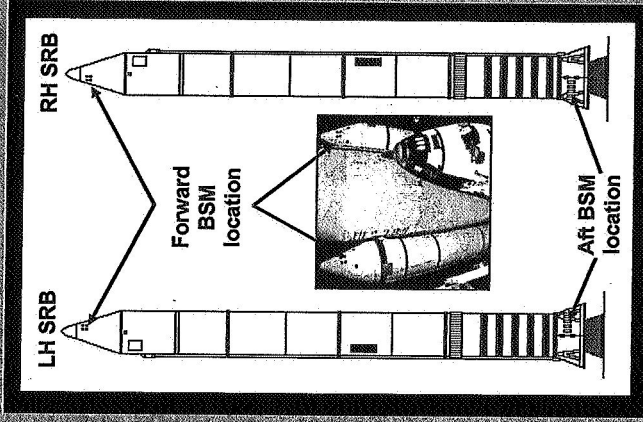


- Bolt catcher redesigned to increase margin of safety
- NSI pressure cartridge redesigned to eliminate NSI ejection



SRB Return to Flight

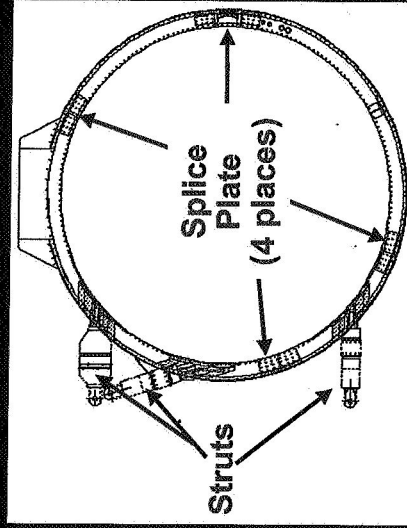
Booster Separation Motor (BSM) Igniter Redesign



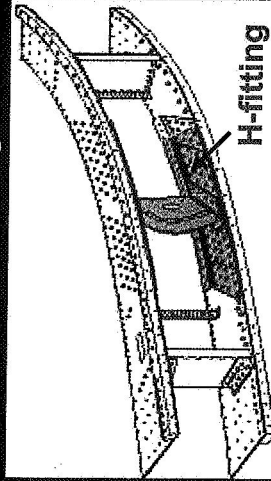
- **Booster Separation Motor Igniter redesigned to eliminate erratic performance**

SRB Return to Flight

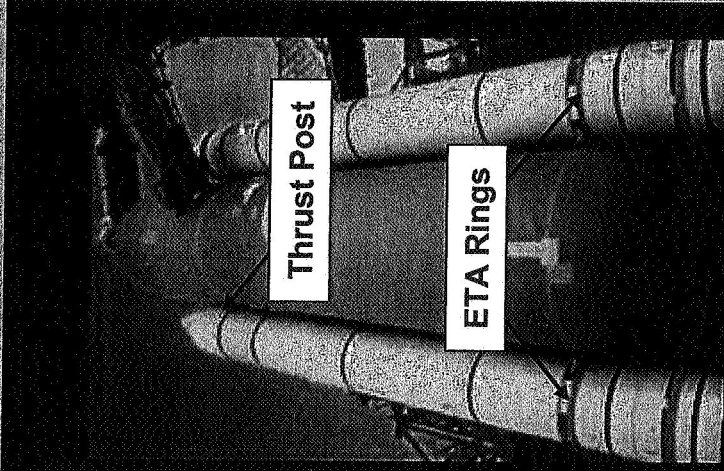
External Tank Attach (ETA) Ring



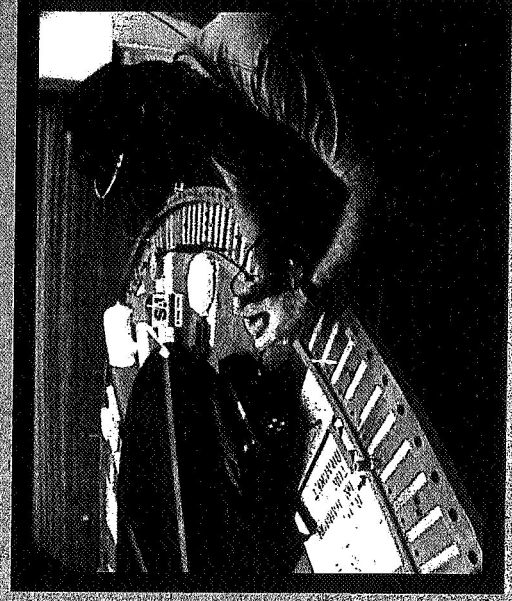
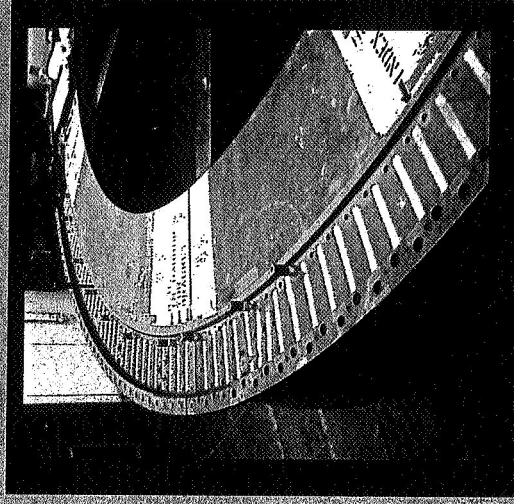
LH ETA Rings



Ring Segment



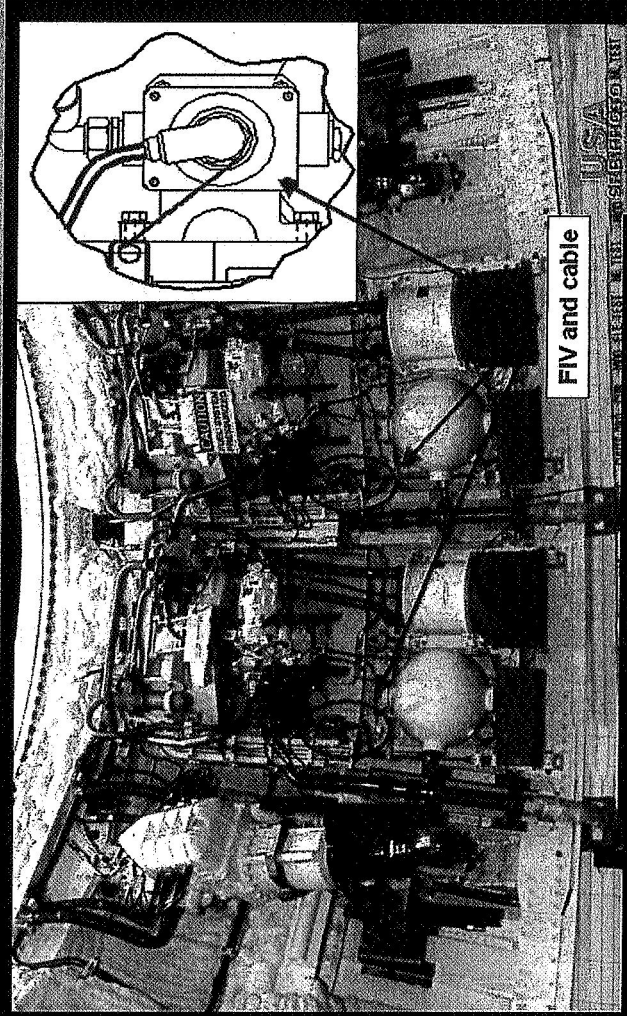
Location of ETA Rings



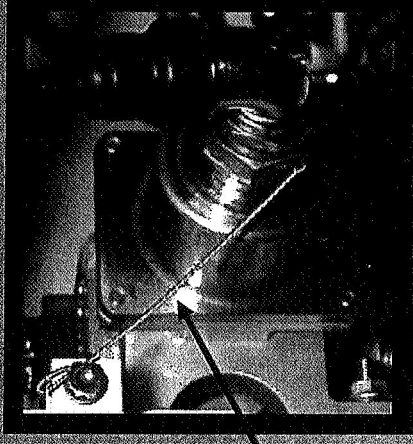
- Implement 4340 Steel ETA Ring

SRB Return to Flight

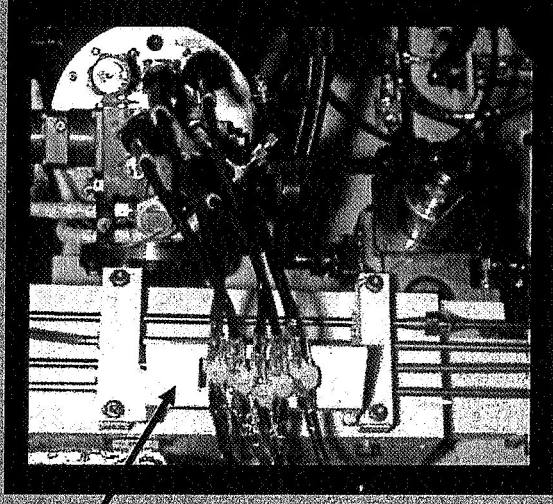
Fuel Isolation Valve (FIV) Connector and Backshell



TVC System Typical Installation



Safety Wire



Support Bracket

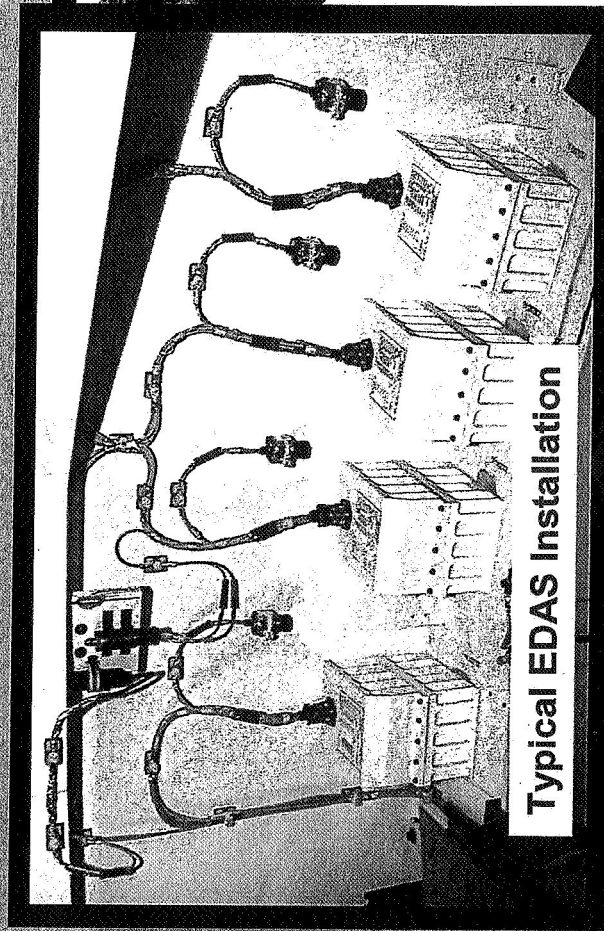
- Enhanced cable securing
- New bracket added to installation
- Reduces length for unsupported cable
- Lockwire replaced Loctite on connector threads

SRB Return to Flight

External Tank Instrumentation



- Enhanced Data Acquisition System (EDAS) used to record 13 ET measurements

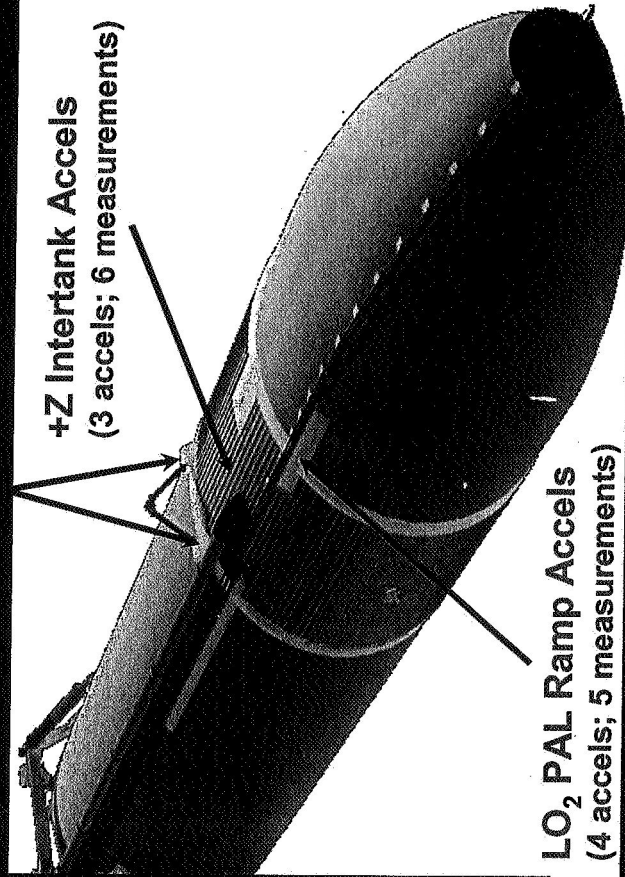


Typical EDAS Installation

Bipod Temperatures
(2 RTDs; 2 measurements)

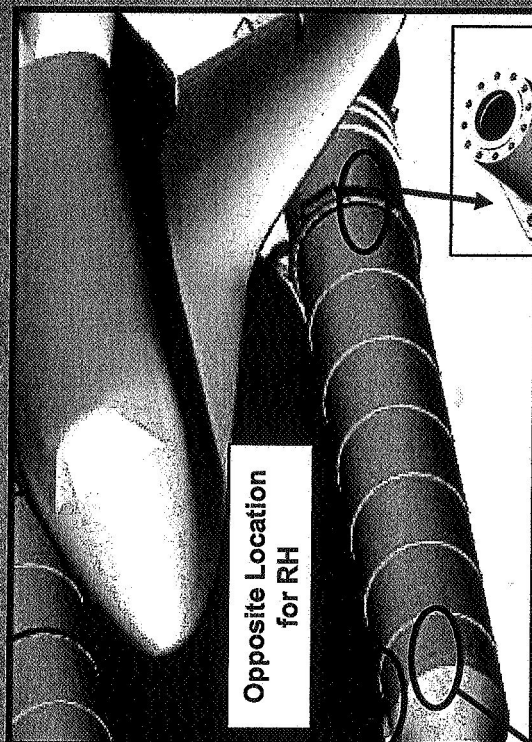
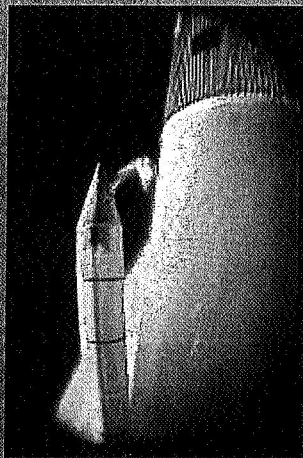
+Z Intertank Accels
(3 accels; 6 measurements)

LO₂ PAL Ramp Accels
(4 accels; 5 measurements)



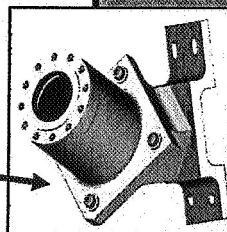
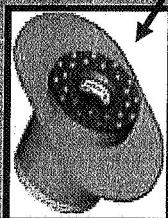
SRB Return to Flight

SRB Camera System



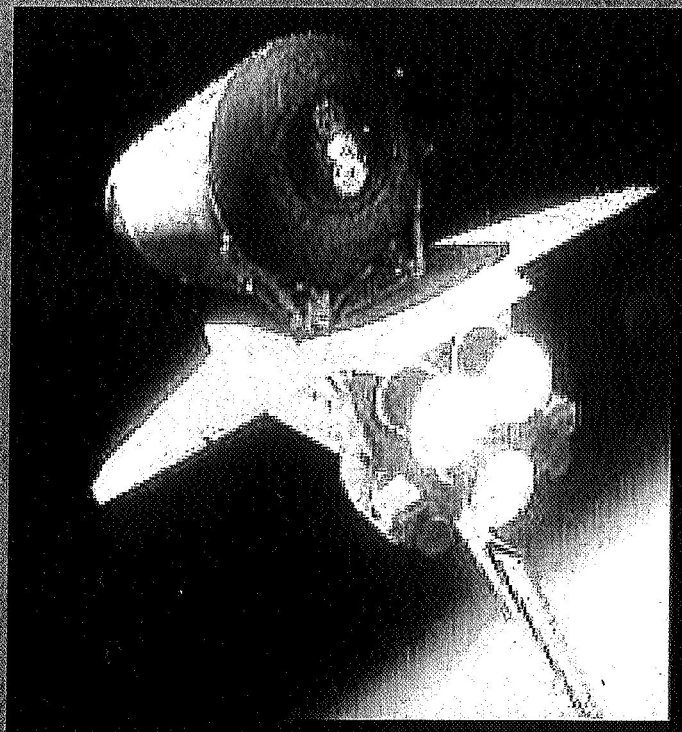
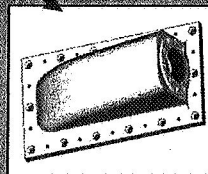
Opposite Location
for RH

ET
Observation
Camera



ETA Ring
Camera

Forward
Skirt
Camera



Play
Video

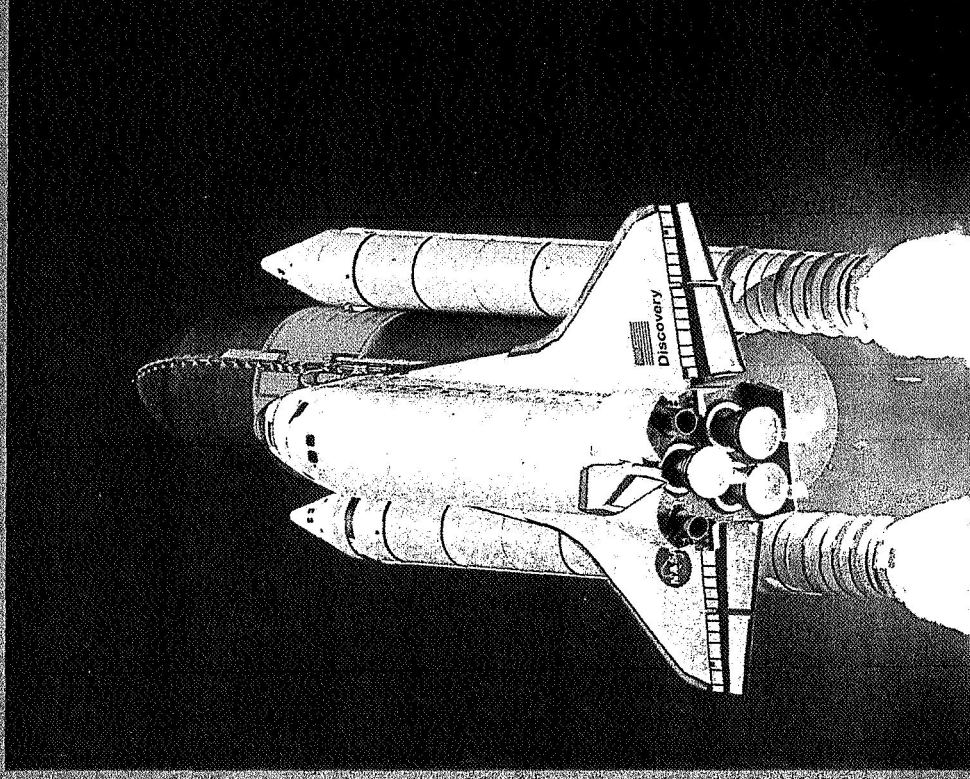
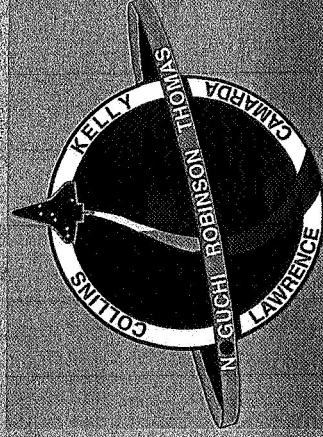
Return to Flight: *Discovery*



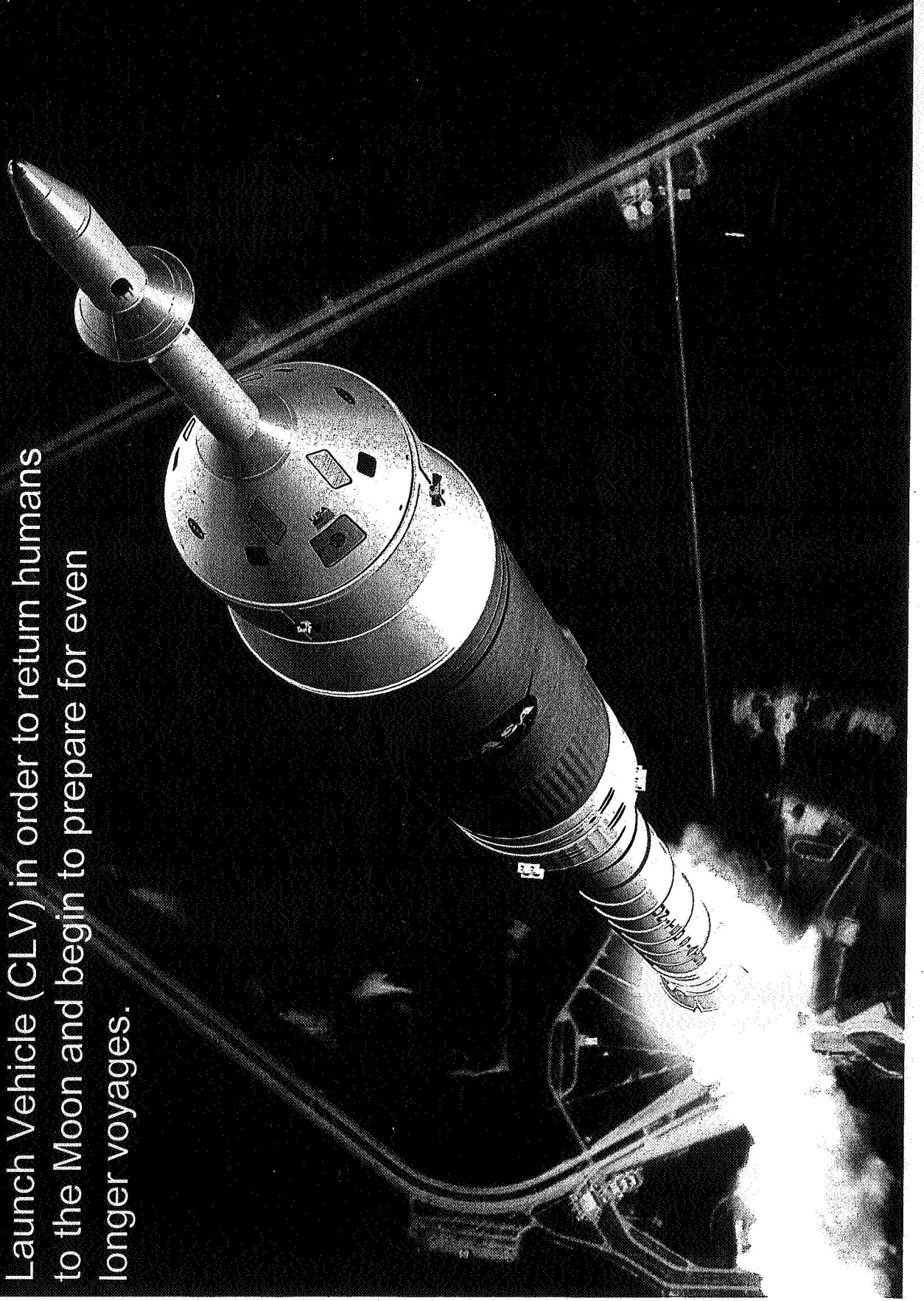
On July 26, 2005, Space Shuttle *Discovery* was launched during STS-114.

Two weeks later, the mission concluded with a successful landing at Edwards AFB, CA.

Continued with STS-115.

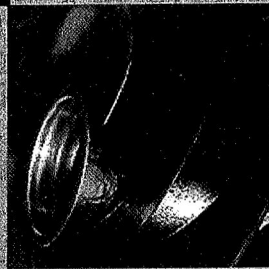
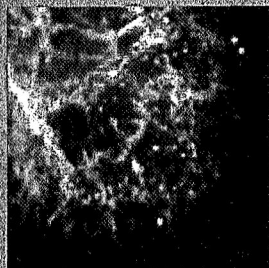


NASA's Constellation Program is developing the Crew Exploration Vehicle (CEV) and Crew Launch Vehicle (CLV) in order to return humans to the Moon and begin to prepare for even longer voyages.





Questions and Answers



www.nasa.gov/centers/marshall

